A Revolutionary Approach to High Energy Density, Low-Cost Aqueous Li/S Batteries

TEAM: PolyPlus Battery Company

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Technology Overview

- Li_2S is > 3,000 times more more soluble in water than in non-aqueous electrolyte
- Superb solubility of Li_2S and higher polysulfides greatly improve reversibility of positive electrode
- Aqueous solutions of Li_2S_x have 50 times higher Li^+ conductivity than non-aqueous analogues
- Aqueous Li/S battery chemistry improves all aspects of cell performance relative to non-aqueous electrolyte

Aqueous lithium polysulfides

Current Status

- Aqueous polysulfides can be blended to increase the ionic conductivity, chemical stability, solubility of both Li_2S and Li_2S_x species
- Aqueous Li/S cells can be cycled at exceptionally high positive electrode capacities with no evidence of parasitic H_2 evolution
- PolyPlus identified and optimized highly porous (and lightweight) hydrophilic carbon cloth structure for aqueous Li/S cells
- PolyPlus developed a unique high capacity PLE to match the aqueous polysulfide electrode
- Thin, flexible solid-state anodes are necessary to achieve 600 Wh/l, 400 Wh/kg target

Project Statistics

Award Amount	$4.5 M
Award Timeline	2/6/2013 – 3/31/2016
Next Stage Target	600 Wh/l, 400 Wh/kg (10 Ah)
Partners Sought	Strategic Investors

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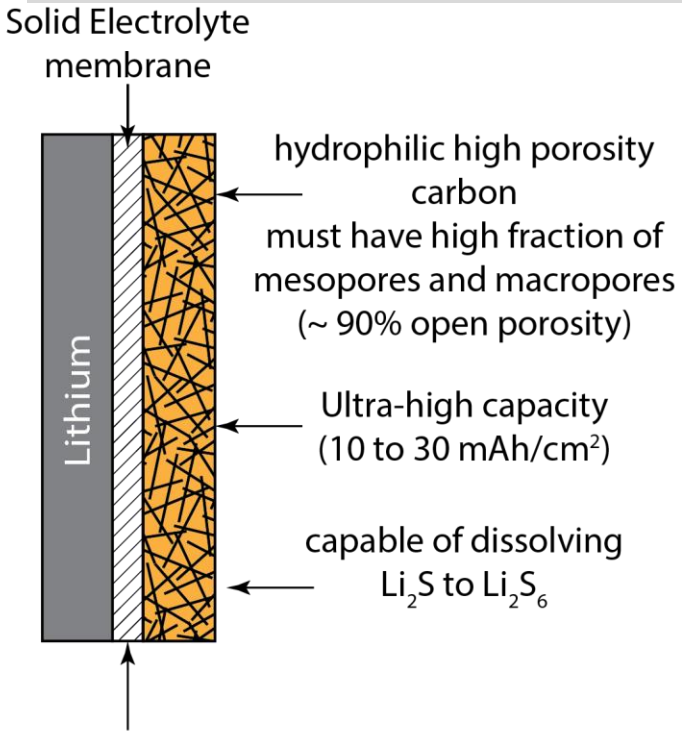
Aqueous Li-S Cell

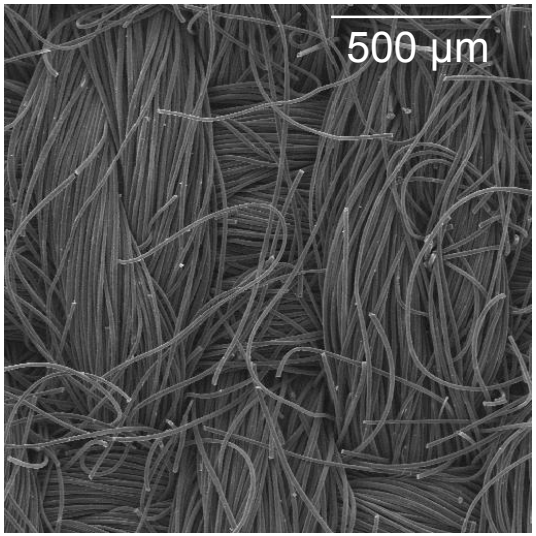
- Pure H_2O is not good enough for high performance cells
- PolyPlus found that blending of H_2O and a non-aqueous solvent greatly improves Li-S cell performance
- Blended catholytes are chosen with the following metrics:



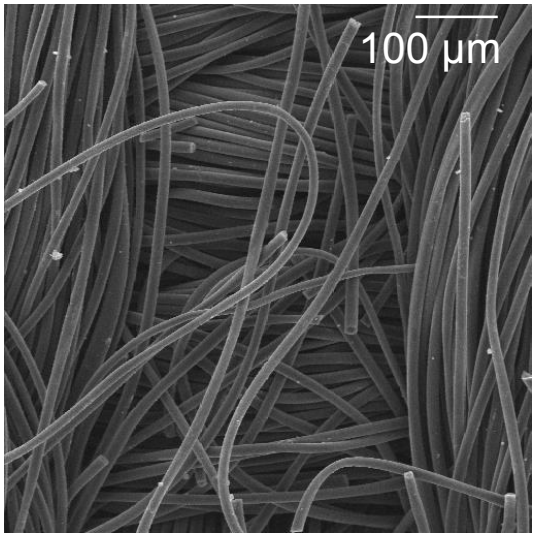
1. Electrochemical stability - no evidence of oxidation or reduction of the electrolyte blend over the potential range of interest
2. Ability to dissolve high concentrations of lithium polysulfides (Li_2S_x)
3. High ionic conductivity of Li_2S_x solutions in the range of 10 MS to 17 MS
4. Chemical stability (no precipitation or color change over several months of storage)
5. Reversible cycling of high capacity Li_2S_x in Li-S laboratory cell using carbon cloth electrode

Hydrophilic Carbon Matrix with Meso and Macro Porosity is Critical to Li-S Cell Performance

SEM Images of 500 µm Thick Carbon Cloth (Grade 2, Japan)



100x



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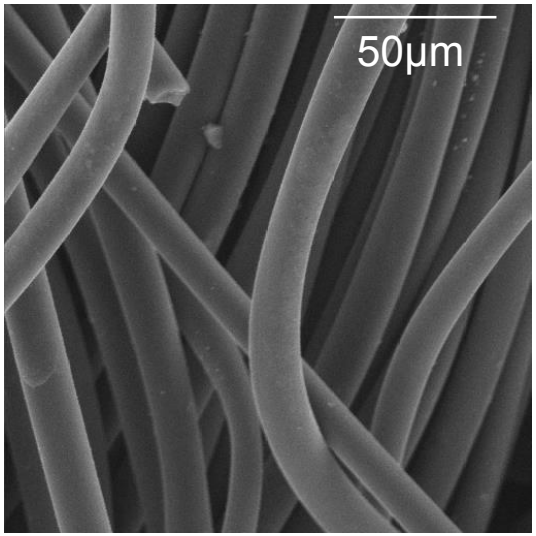

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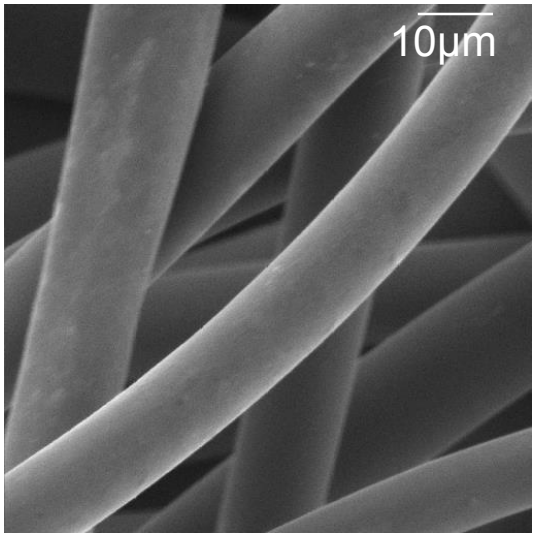

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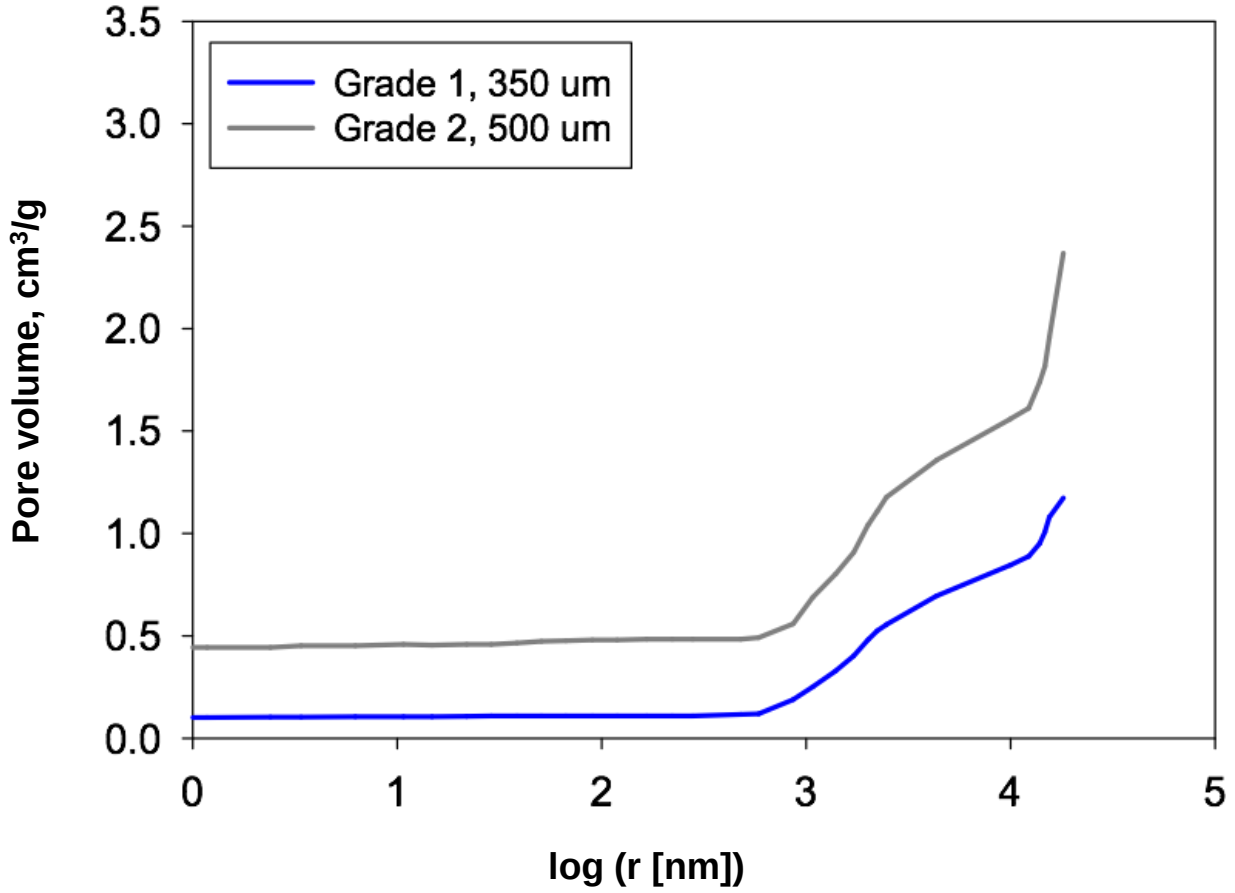
Comparison of Integral Pore Size Distribution Curves of Two Carbon Cloths (500 um Grade 2 and 350 um Grade 1,)



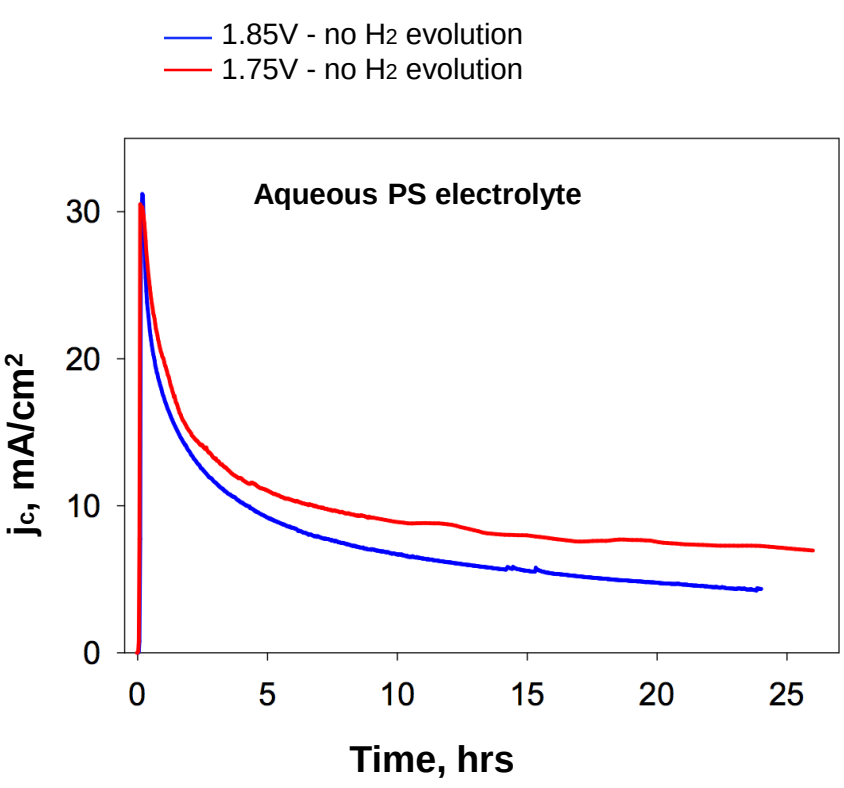
Grade 1 cloth has lower total porosity and specific surface area than Grade 2 cloth

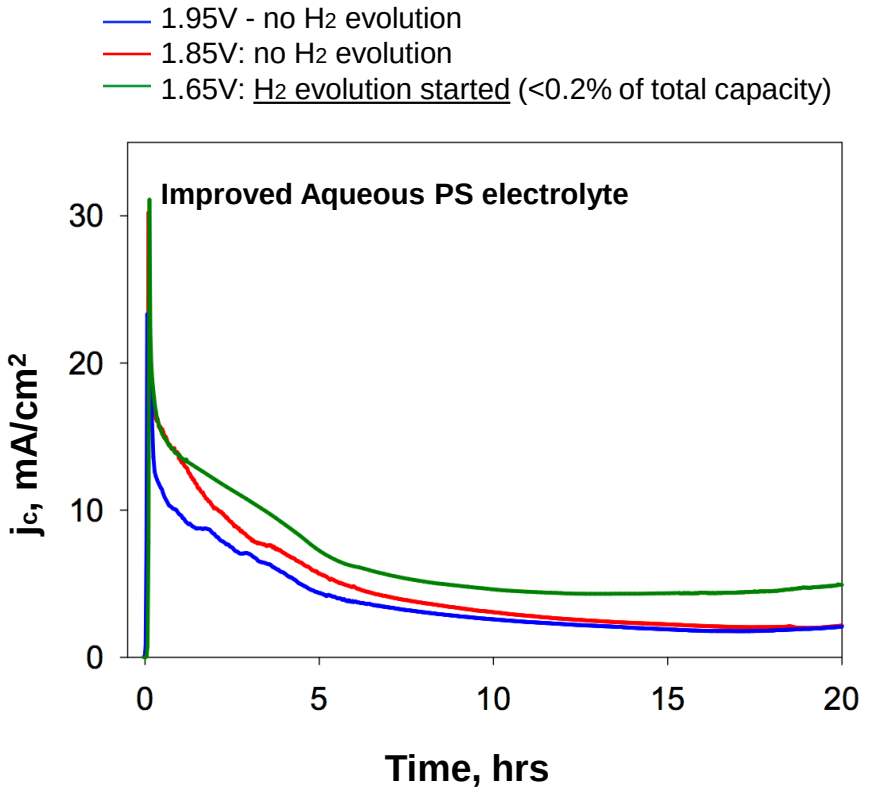
Similar large macroporous structure

Grade 1 cloth has much lower volume of micropores than Grade 2 cloth

Determination of Operational Voltage Stability Window: Chronoamperometry on Carbon Electrode in PS Electrolytes

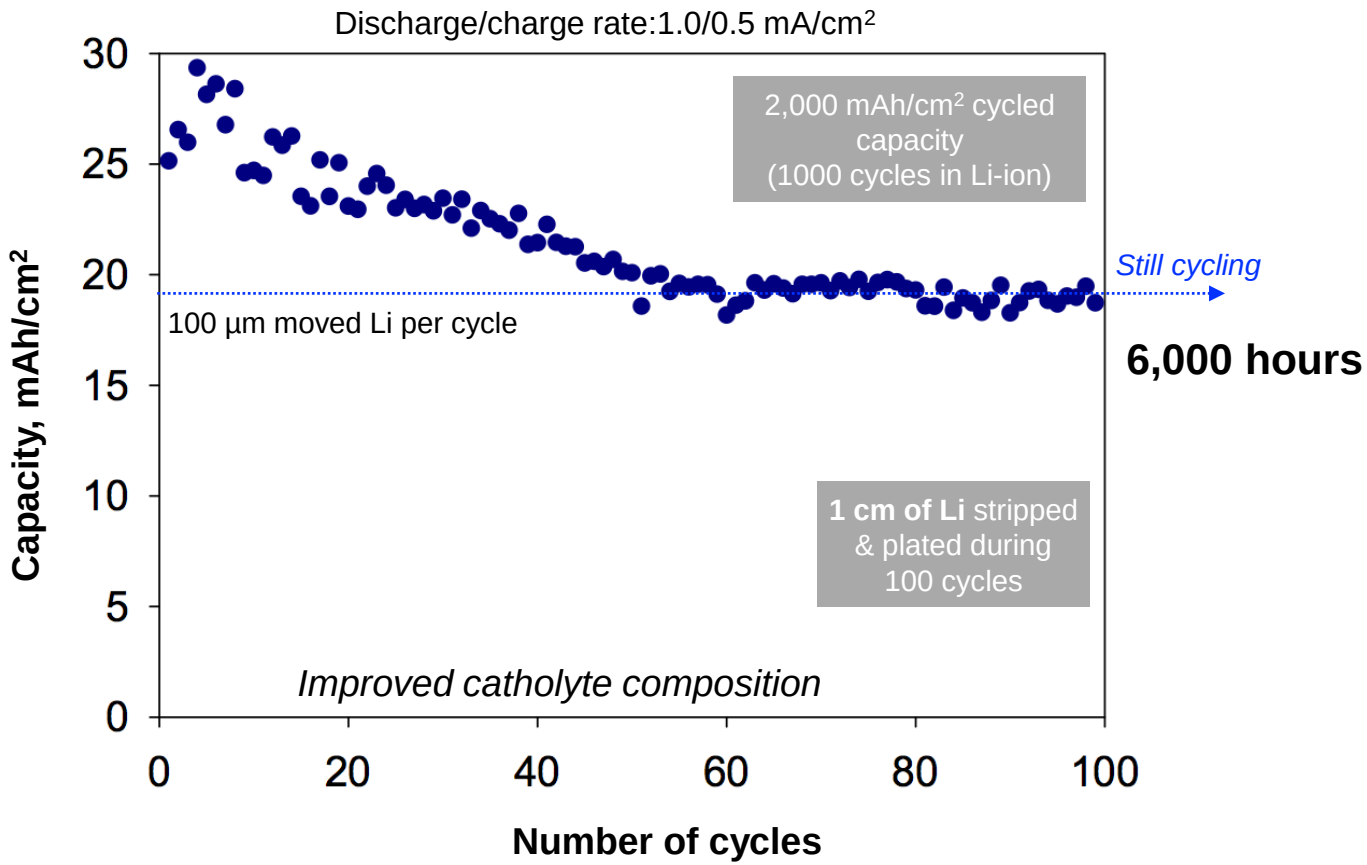
Carbon cloth electrode



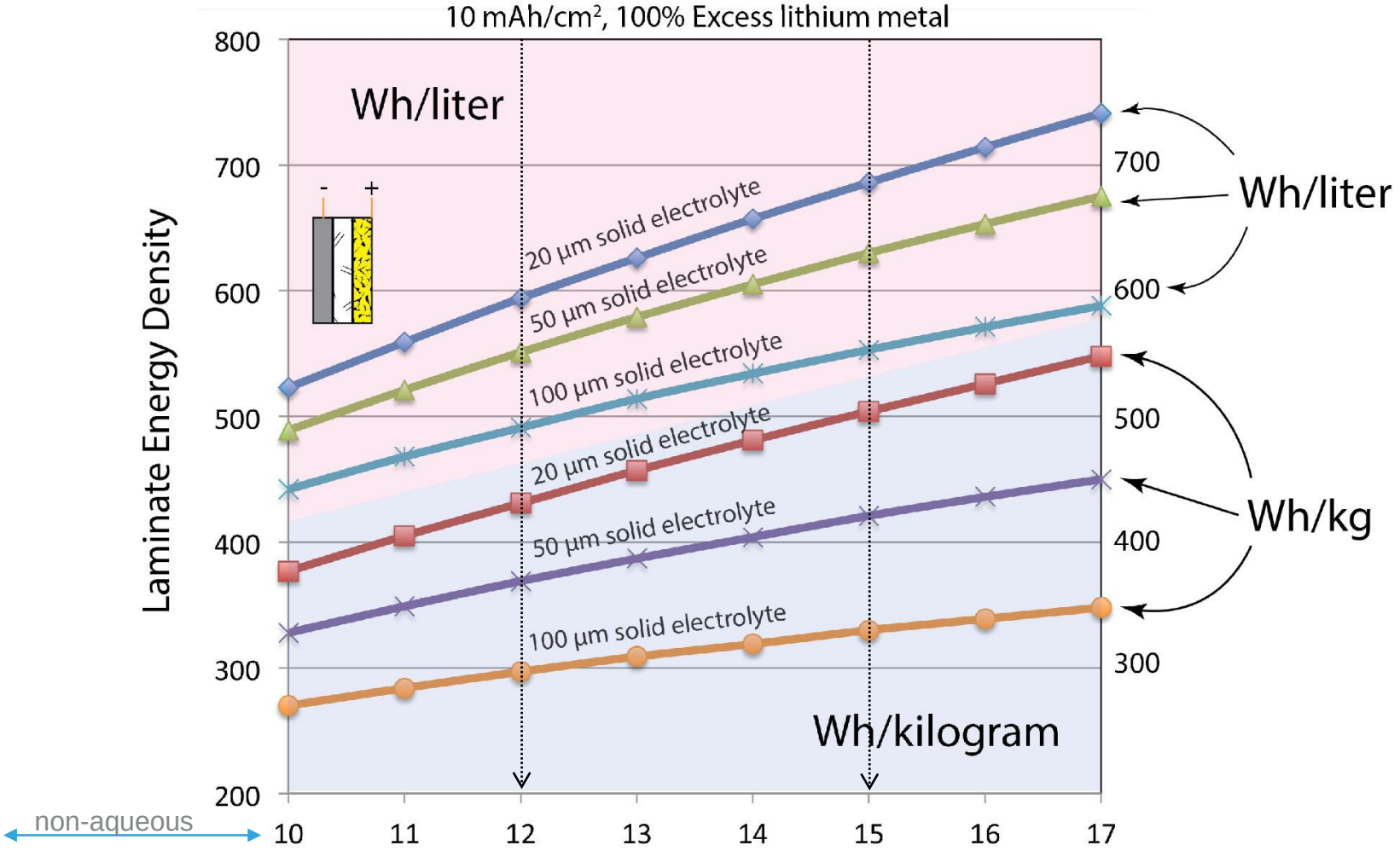


Cycling Performance of Cells with 12 M S Aqueous Catholyte 450 µm Carbon Cloth Cathode Grade 2.0

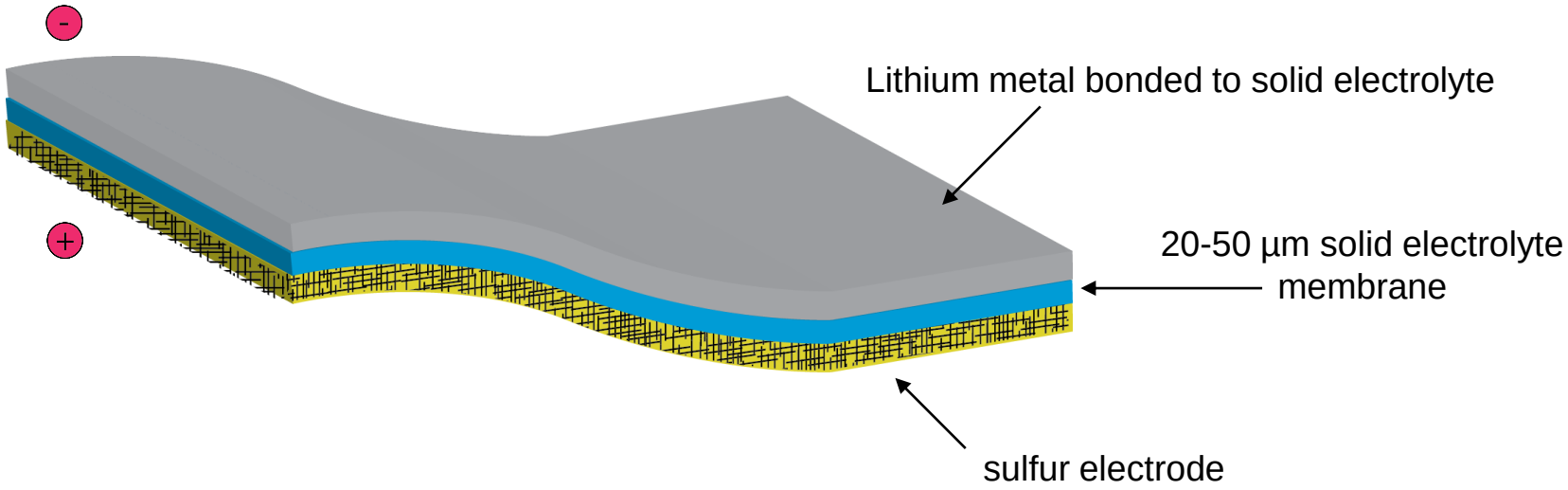
Catholyte: 12 M S Li_2S_5 in 20% 2-non-aqueous, 80% H_2O



Energy Density Projections



Tech to Market



- *PolyPlus is building team now*
- *Approach is highly scalable at low cost*
- *Will be enabling for Li/S and other chemistries*